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Evaluation of Spatial Resolution in the Phase II Microvision, Inc. Aircrew Integrated Helmet System HGU-56/P Scanning Laser Display

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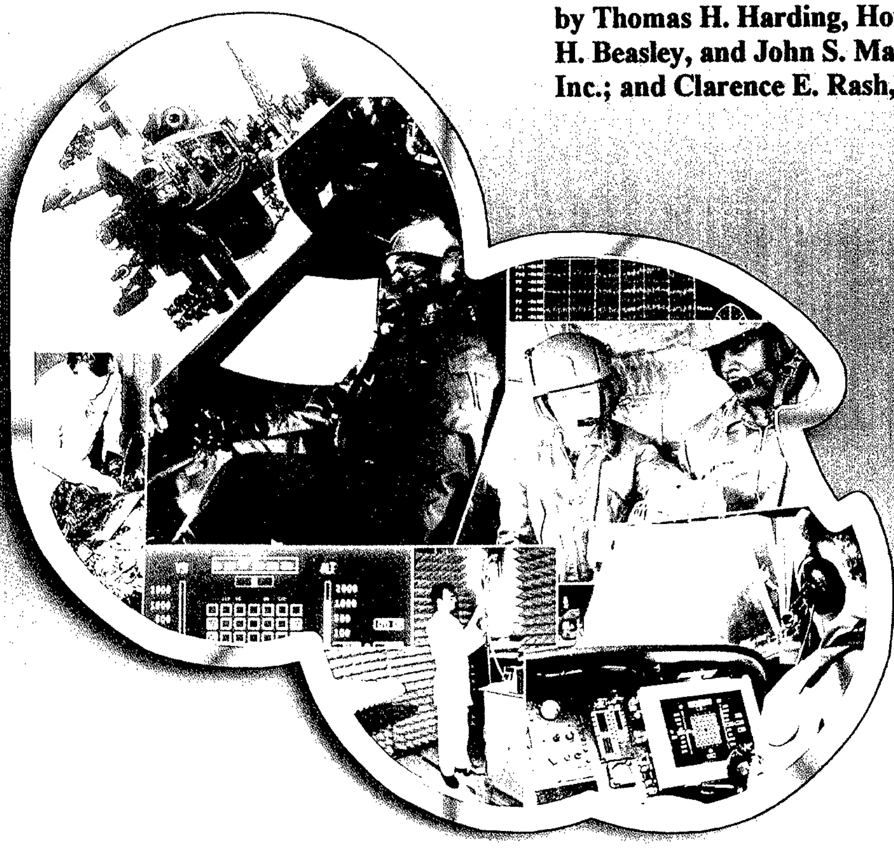

Aircrew Health and Performance Division

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The final Phase II version of the Microvision, Inc., Aircrew Integrated Helmet System (AIHS) HGU-56/P scanning laser display was evaluated for spatial resolution performance. The data reported herein show an improvement in the modulation transfer function (MTF) over the Phase I system. The following modulation values, which meet the RAH-66 Comanche specifications, are: 0.10 horizontal MTF and 0.24 vertical MTF.

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Introduction

The Project Manager, Aircrew Integrated Systems (PM-ACIS), Huntsville, Alabama, has established a program with Microvision, Inc., Bothell, Washington, to develop a technology demonstrator to determine the capability of a scanning laser display to meet RAH-66 Comanche helmet-mounted display (HMD) performance specifications. Under this program, titled Aircrew Integrated Helmet System (AIHS) HGU-56P program, Microvision developed and delivered to the Army a prototype laser-based HMD for evaluation by the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama. USAARL Reports No. 99-18 (Rash et al., 1999) and 2001-06 (Harding et al., 2001) provided evaluations of earlier versions of the Microvision, Inc., HMD. This report constitutes the findings of an evaluation of the Phase II HMD, which incorporates design improvements into the earlier versions. The main improvement comes from the integration of new electronics that allow for enhanced control of subpixel spacing and positioning. Essentially, Microvision, Inc. made changes to the system to improve the horizontal modulation transfer function (MTF) of the system, especially in the horizontal MTF at the Nyquist frequency.

A full description of the Microvision HMD system can be found in a previous report (Harding et al., 2001) and the system only will be described briefly here. For each side of the binocular display, light from a laser beam is divided into two beams for simultaneous scanning in both forward and retrace directions. This scanning technique reduces the bandwidth requirement for the horizontal and vertical scanners housed in the HMD. Beam intensity is adjusted by electro-optical modulators. In effect, these modulators control the contrast and duration of each pixel as they are drawn by the sweeping beams. Timing circuits control the duration of pixels that change as a function of lateral position. Due to geometry, pixels in the lateral periphery have shorter durations than pixels in the lateral center. To draw a single vertical line, the horizontal scans must be turned on at a certain point and then turned off. To draw the best line possible (narrowest lateral profile), the beams must be well calibrated and aligned, and the timing circuits must maintain consistency from the top of the field to the bottom of the field. In past Microvision systems, the vertical line profiles have been substantially wider than the horizontal line profiles. The result of which has been directly observed in the vertical line's MTF (termed the horizontal MTF; since in frequency space, vertical lines are composed of horizontal frequencies).

This Microvision HMD has new electronics, which were developed to address the positioning of pixels more precisely. Positioning pixels in a vertical line more accurately will lead to an improved MTF. Further, Microvision appears to have reduced the timing signature of each pixel, which also will aid in the improvement of the MTF. This can be likened to reducing the fill factor in flat panel displays. However, this reduction has led to other problems (see contrast transfer function (CTF) noise below).

The results presented here are limited to spatial resolution and were taken during the first week of testing when onsite support was provided by a Microvision, Inc. engineer.

Subsequently, difficulty was encountered in properly aligning the system, and the imagery produced was of poorer quality than that seen earlier. The current system hardware seems “fragile,” as alignment procedures had be performed prior to each test procedure, and this alignment does not maintain over night. In addition, "warm-up" periods as long as 1 hour were required prior to evaluation. Also, the left-side video board failed to produce imagery equal in quality to that of the right-side video board during testing. Therefore, the right-side video board was used to drive both sides during the tests reported here.

Photographic measurement of spatial resolution

To avoid the problems of temporal noise affecting measurements, we used still-photography to capture HMD imagery using a quasi-linear charge-coupled device (CCD) camera and a computer capture card. Software allowed us to evaluate the images by converting the unsigned gray shade values (8 bits of resolution) into whole numbers (0 to 255) for numerical analysis. Image capture was aided by a device, built by USAARL, which maintained alignment of the camera lens with the HMD’s exit pupil (Figure 1). In most cases, laser intensity was adjusted to produce photographic images where the gray-levels ranged over the whole 8-bit range without saturation. It should be noted, the noise characteristic of our measurement system was not considered in these calculations. Removing the bitmap noise from the data would likely have a positive affect by showing higher contrast and modulation levels than those reported here. This shortcoming is inherent in the photographic method but can be reduced by using cameras better suited for mensuration.

Modulation transfer function (MTF)

The Microvision HMD uses a display format of 1280 by 960 pixels. Using an approximate field-of-view (FOV) of 41 degrees by 30.75 degrees, one-degree square of visual angle contains approximately 975 pixels (31.22 pixels per linear dimension). This relates to a Nyquist frequency of 15.61 cycles/degree ((31.22 pixels per degree)/2). In the previous system, the horizontal MTF barely showed measurable modulation at the Nyquist frequency (Figure 2). The RAH-66 Comanche specification calls for an 8-percent modulation at this frequency.

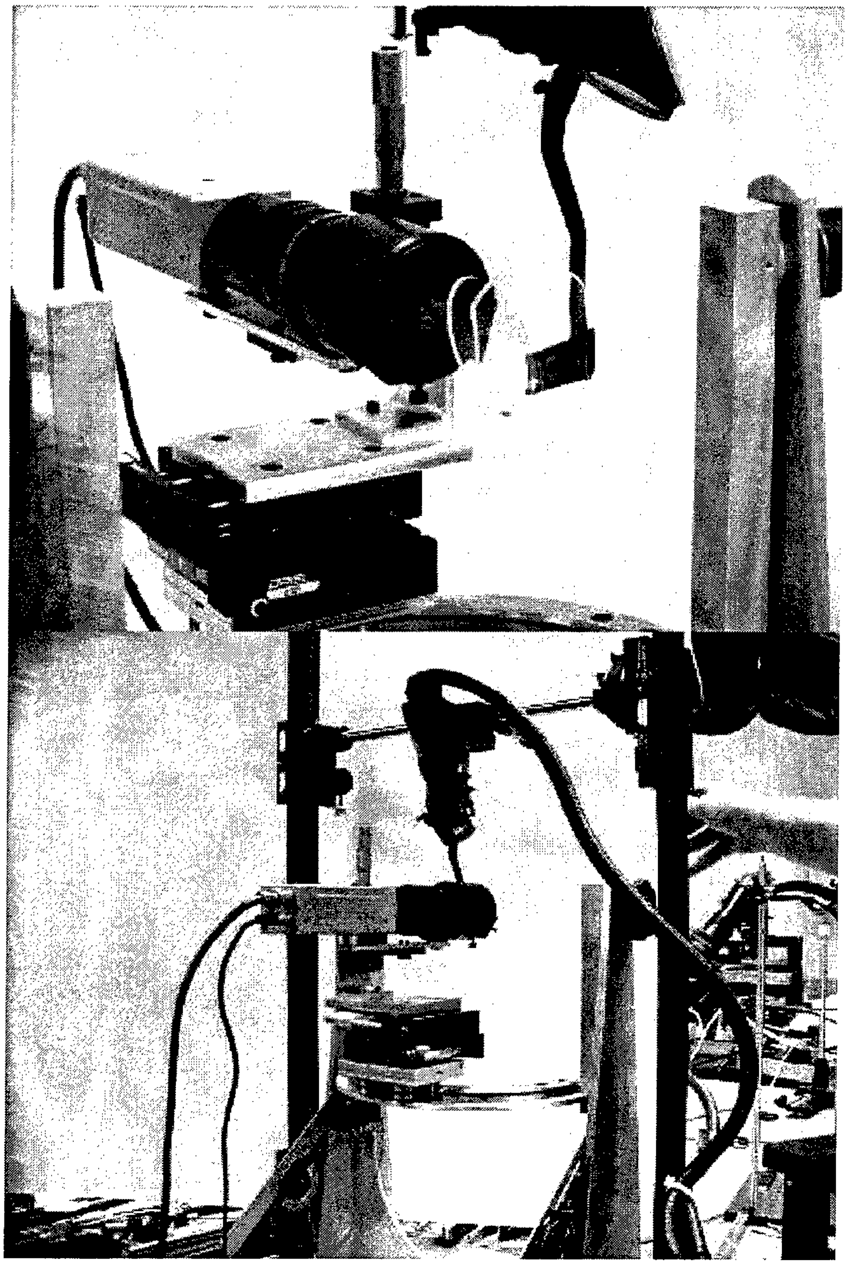

Figure 1. Photographs of optical set-up showing relationship between the HMD optics and camera lens. In the top photograph, note the image of the exit pupil centered on an artificial 3mm iris. For all of the data shown in this report, a 5mm iris was used. The device holding the camera allowed viewing of any FOV position while still maintaining correct alignment.

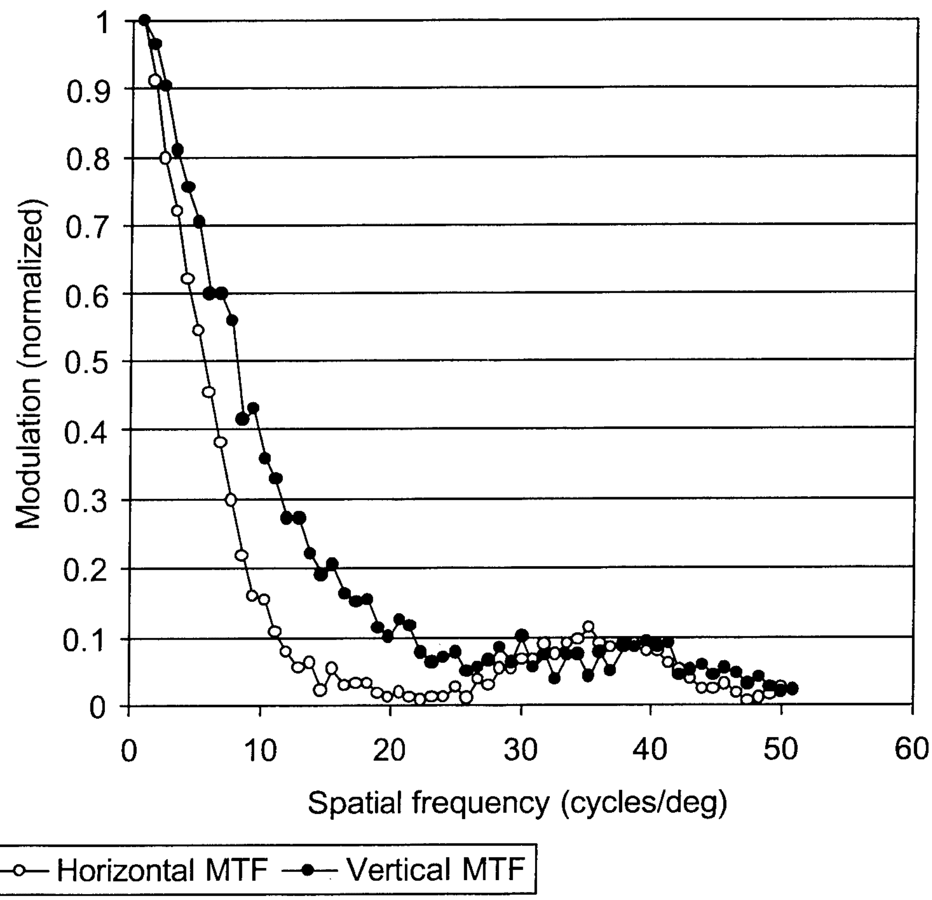

Figure 2. Vertical and horizontal MTFs measured previously (Harding, et al., 2001). Note the difference between the two curves at the Nyquist frequency (horizontal = 0.05 and vertical = 0.20).

Central monocular area MTF

To make comparative measures and to evaluate Microvision's design progress, line spreads were measured for the horizontal and vertical orientations with the system well calibrated and the HMD imagery properly aligned with the camera. Figure 3 shows photographic images of the horizontal and vertical lines captured from the left-side optic. Figure 4 shows the MTFs obtained from these photographic images. Note the increase in modulation at the Nyquist frequency for the horizontal MTF.

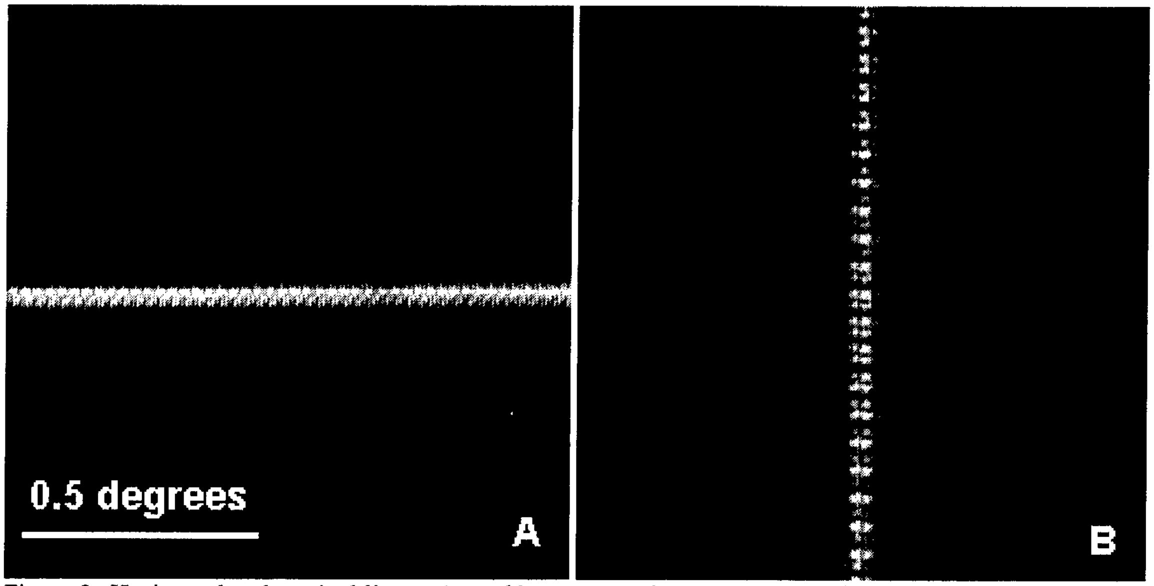

Figure 3. Horizontal and vertical lines captured by a grayscale camera. These lines reflect the best imagery we obtained from the system.

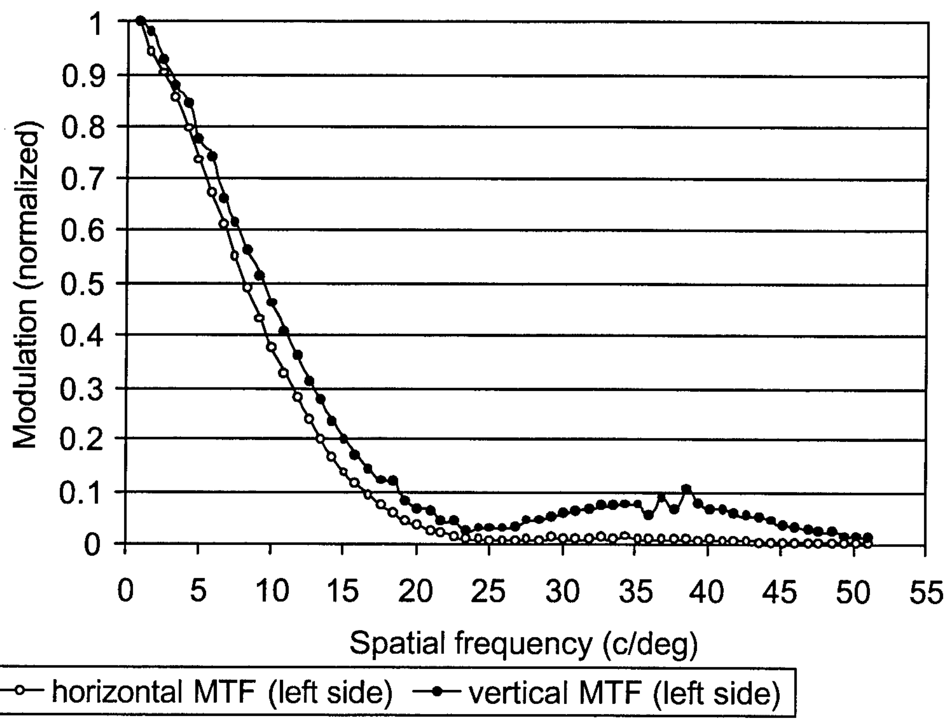

Figure 4. MTFs measured from the left side of the HMD. Like before, the vertical MTF shows about 0.20 modulation at the Nyquist frequency. The horizontal MTF showed modest improvement with about a 0.12 modulation at the Nyquist frequency.

The horizontal MTF shows modest improvement in that the performance exceeded the Comanche specification. These curves were taken from lines well centered in the middle of the 1280 by 960 pixel array.

Central binocular area MTF

Since the HMD design is biocular with a binocular overlap, the nasal 25 degrees from each side is overlapped. It is important to assess the MTF in the middle of the overall FOV. To accomplish this, we captured line profiles at 12.5 degrees from the nasal edge. Figure 5 shows MTFs calculated from the photographed line profiles from the left side. Little difference was observed between the peripheral MTFs and the central MTFs. We had expected modest differences based upon Microvision's reported data from the left and right periphery, yet found no noticeable performance fall-off. This bodes well for binocular viewing as the MTFs exceeded the Comanche specification at the Nyquist frequency.

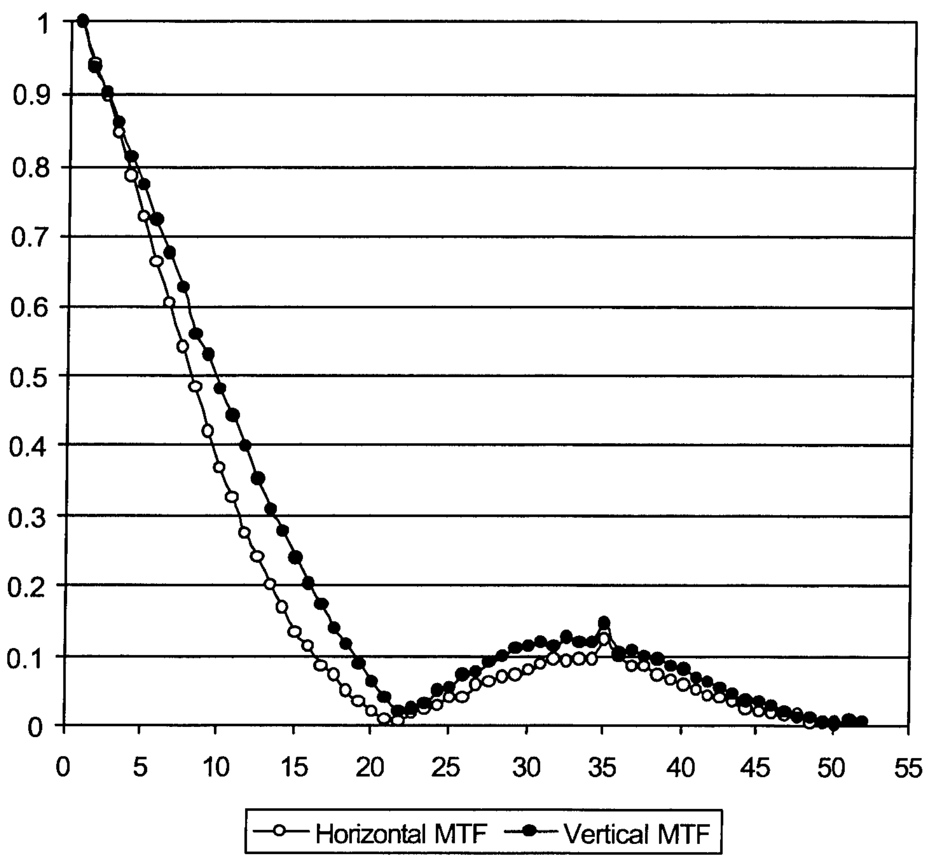

Figure 5. MTFs taken from the left side for lines centered 12.5 degrees from the nasal edge.

Point spread function (PSF)

Microvision had found higher modulation at the Nyquist frequency by calculating the MTF from the PSF. In a linear system, the line spread and point spread should provide the same frequency information for a single dimension. However, Microvision's laser

scanning technique produces spatial images that are noncontinuous, and multi-pixel patterns cause spatial inconsistencies that weaken the system's spatial resolution. For example, at the Nyquist frequency, a grill pattern's fast Fourier transform (FFT) contains considerable noise (unwanted spatial frequency modulation) that degrades an observers' ability to identify the orientation of the grill pattern (see CTF noise below).

Thus, we feel that the PSF may inflate the actual frequency response of the HMD. As a casual aside in support of this notion, the geometry of vertical and horizontal lines is not constant, but rather is dependent upon scaling and/or various alignment procedures. For example, often, a single line may look like a rope with a spiral geometry and, at other times, the spiraling is not readily observed. This geometric inconsistency would produce line spreads that are different. Thus, we feel that MTFs based upon line spreads provide more accurate data. In an attempt to duplicate Microvision's conclusions, we measured the MTF from a PSF. A photographic image of a single pixel in the middle of the FOV is shown in Figure 6.

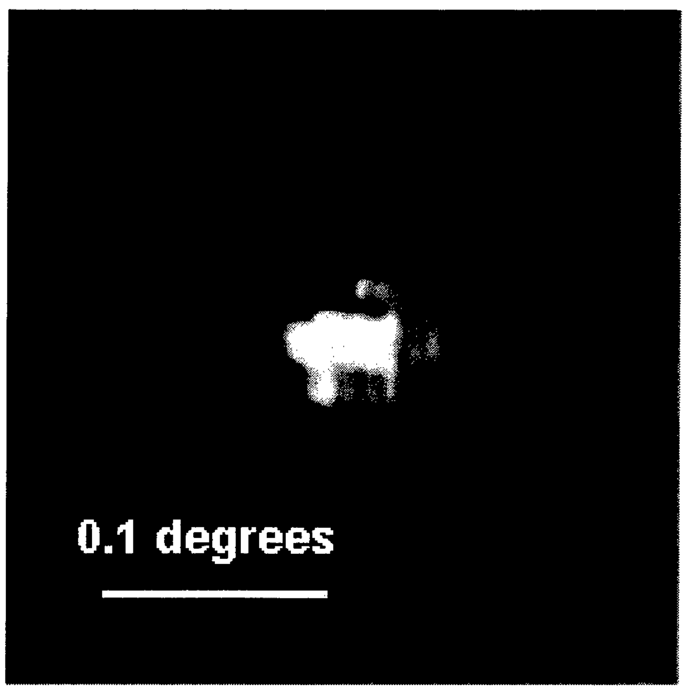

Figure 6. Enlarged photographic image of a single pixel located in the middle of the FOV. The photographic image is 64 by 64 pixels that represents a square field of about 0.3 degree in each dimension. Note the essential ghost duplication in the mage. For our measurement of the PSF, we used an image size of 256 by 256, in order to add resolution.

Figure 7 shows the spectral distribution calculated from the pixel shown in Figure 6. Calculating the modulation at the Nyquist frequency, we found a modulation depth of 0.10 (horizontal MTF) and 0.24 (vertical MTF).

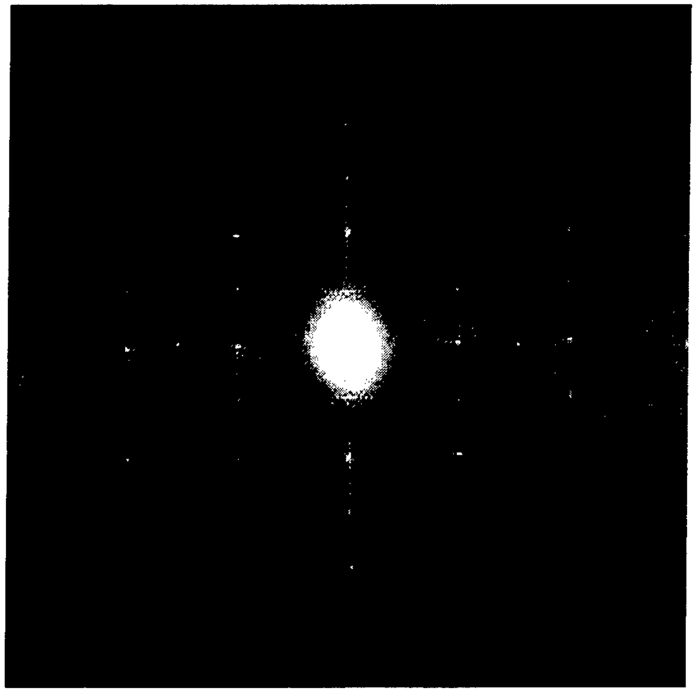

Figure 7. Photographically enhanced two dimensional frequency spectra of pixel image in Figure 6. Prior to the two-dimensional FFT, the dc (gray level of 12) was subtracted from the image shown in Figure 6. Note the rather symmetric frequency modulation.

Contrast transfer function (CTF)

CTFs were measured using different techniques in order to better characterize the spatial resolution of the system. Following vertical or horizontal alignment, photographic images of grill patterns were collected. As a side note, HMD imagery did not produce orthogonal rows and columns. They were about 2 degrees off normal. Thus, realignment was necessary when measuring contrast between rows and columns. In our measurements, alignment was critical because data were collapsed in one axis (dimension) to produce an average modulation in the other axis. For example, to measure the contrast for a horizontal grill pattern, data were collapsed horizontally over a number of data points to produce a one-dimensional curve.

The first CTF measurement technique was rather straightforward. Maximum contrast was measured by averaging the peaks and troughs in the collapsed data to determine an average peak and an average trough. Figure 8 shows data collected from the 1-on/1-off grill pattern. The peak was the average of the five peaks identified in the chart. Likewise, the trough measurement was the average of the six troughs. Using this technique, horizontal and vertical CTFs were measured for the left side (Figure 9). The 0.25 contrast value measured for the vertical 1-on/1-off grill pattern represents a major improvement in the system. Last year (Harding et al., 2001), an average contrast of approximately 0.025 was measured for the vertical grill pattern.

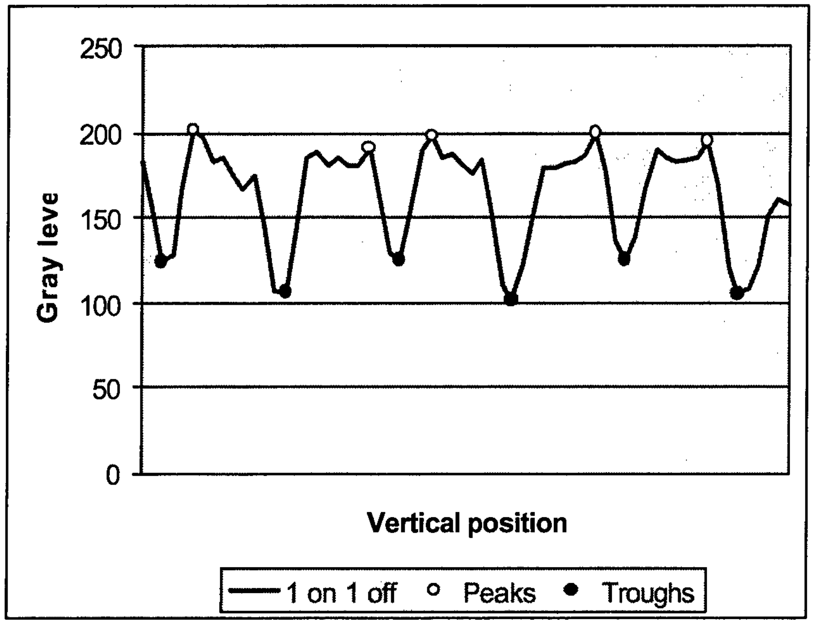

Figure 8. Peaks and troughs used to measure the CTF contrast.

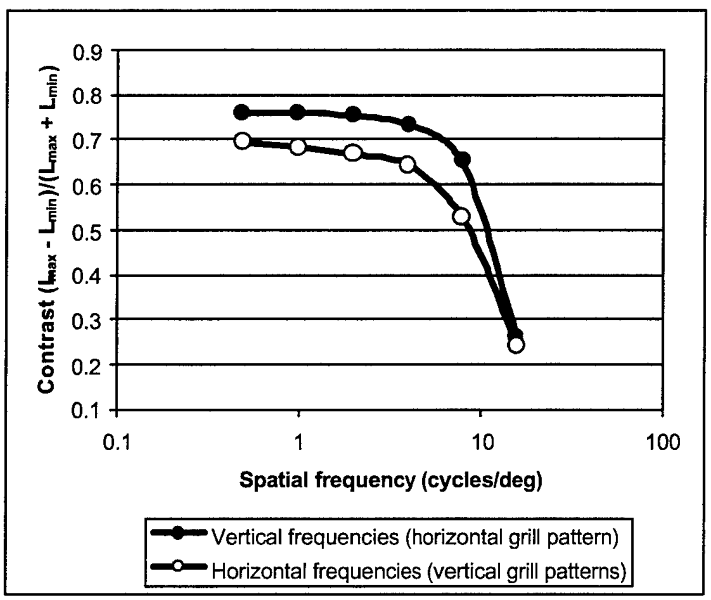

Figure 9. Horizontal and vertical CTFs measured for grill patterns in the left side's central area. Note the sharp fall-off at the Nyquist frequency.

CTF noise

When viewing the HMD imagery at the Nyquist limit, it is difficult to discern the orientation of the grill patterns. In fact, for the vertical grill pattern, an observer is more likely to observe a horizontal grill than a vertical grill. This is a problem with the nature

of the pixel structure. With older CRT systems, there was never a problem in identifying the orientation of grills if given sufficient contrast. However, the Microvision system is a pixilated display much like a flat panel display. Using terminology from flat panels, the pixel geometry in the Microvision system has a fill factor of less than one, i.e., the active pixel does not occupy all of the pixel space represented by the angular subtense of pixel spacing. Thus, the two-dimensional spectra of a grill pattern has spatial frequency content in multiple orientations. Older CRTs had spatial frequency content in only one orientation, per se. This multidimensional frequency content leads to mistaken recognition of orientation. If we consider spatial frequency content that is not in the appropriate orientation as noise, then it is possible to calculate signal to noise ratios for grill patterns.

To simplify the noise calculation, we used a shortcut of collapsing data orthogonal to the orientation of the grill pattern. Figure 10 depicts this method of measuring signal and noise. In Figure 10A, the noise would be the profile at the bottom and the signal would be to the right. The opposite case would be used for the grill pattern shown in Figure 10B.

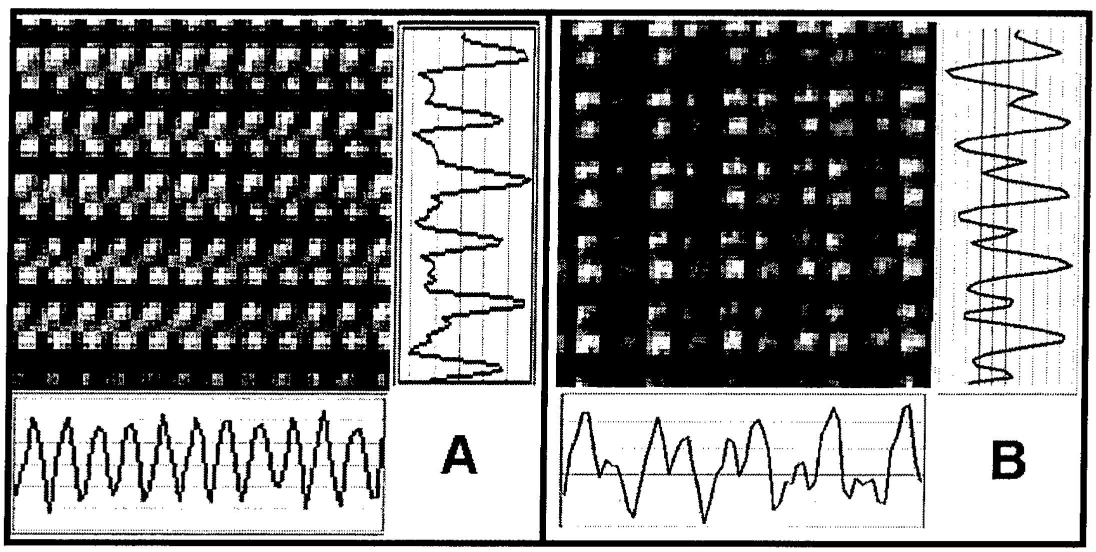

Figure 10. Photographically enhanced images of 1-off/1-on grill patterns in the horizontal (A) and vertical (B) orientations. Of note is the pixel structure observed in B. Here a strong horizontal element is noticed. This element makes recognition of orientation difficult. Profile amplitudes are not necessarily to scale.

In this analysis, a more robust method of measuring contrast was used, which takes into account the variability of the waveform. Standard deviations were calculated for the signal and noise curves. To normalize the data, the standard deviations were divided by the means. Figure 11 shows CTFs measured using this technique. Of particular note, at the Nyquist frequency, the noise contrast for the vertical grill pattern was higher than the signal contrast. This would explain the difficulty in correctly identifying the orientation of the vertical grill pattern. In Figure 12, we plotted the signal to noise ratios for the six spatial frequencies and two orientations. Also plotted in this figure are calculations taken

from images provided by Microvision. With the exception of the one wayward point, the data were nearly identical. This provides additional support for the robustness of the method.

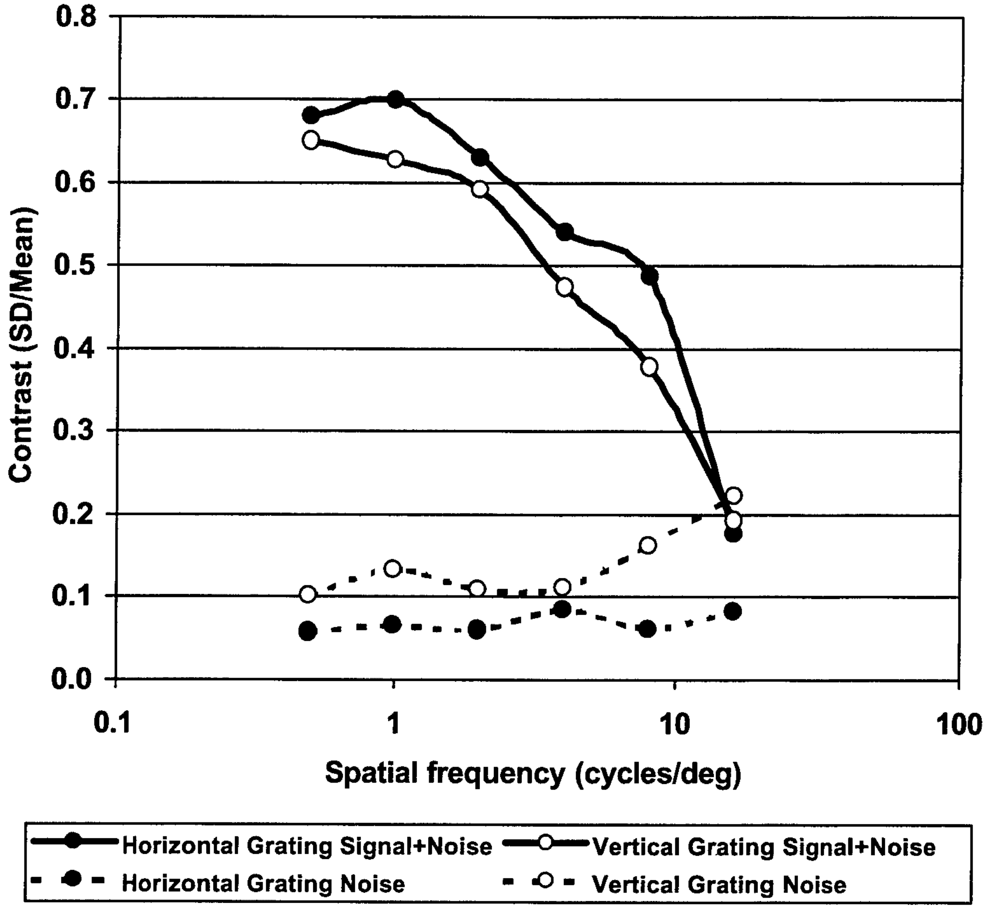

Figure 11. CTFs measured using the standard deviation technique for grill patterns presented to the left side. Here the noise estimates are plotted as a function of grill spatial frequency. As a side note, the noise frequency spectra is highly correlated with the pixel spacing and is thus composed of higher spatial frequencies (near the Nyquist frequency). Since the Nyquist frequency is well within human spatial frequency bandwidth, we feel justified in using our noise estimates in this fashion.

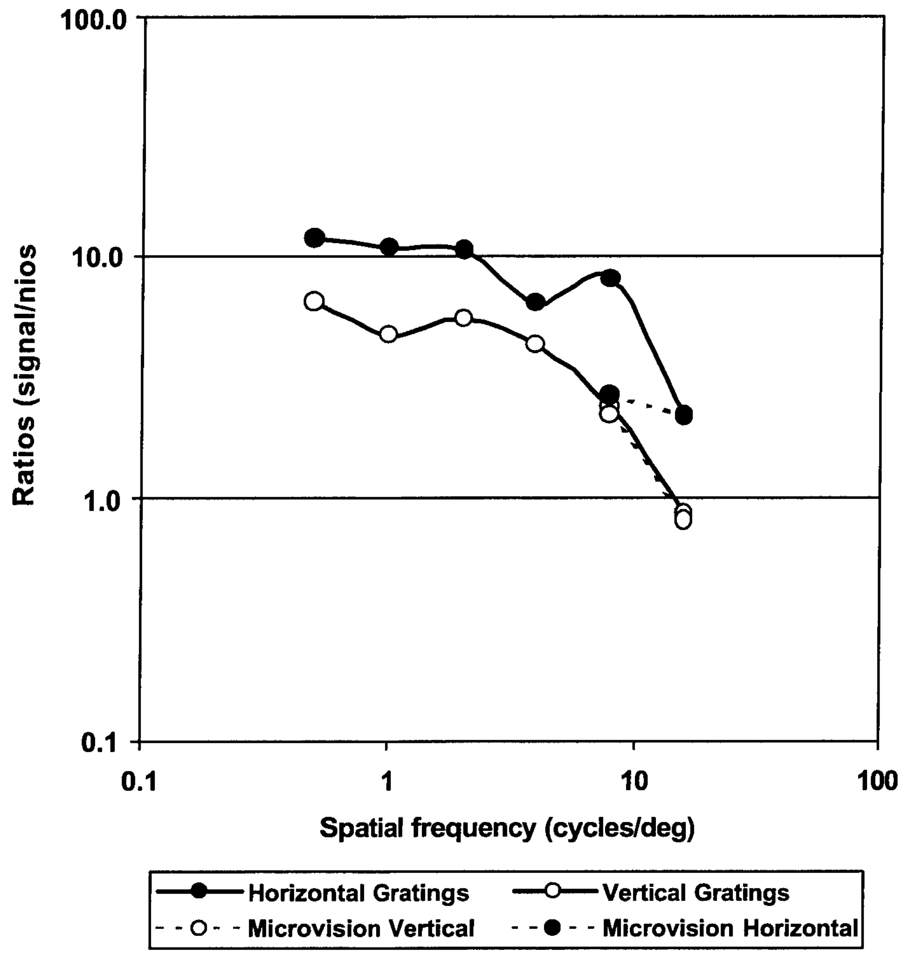

Figure 12. CTF signal-to-noise ratios based upon the data shown in Figure 11. Microvision engineers provided us photographic images of grill patterns used in their data analysis. Using their images, we calculated the signal-to-noise ratios for the highest two spatial frequencies. With the exception of the aberrant point, their data fell on top of our data points.

Character resolution at the spatial limit

To evaluate the system's ability to produce imagery at the spatial limit of resolution, a target consisting of 5 by 5 characters was constructed and presented normally and at 90 degrees rotation. The smallest gap in these characters was one pixel - the spatial limit. Figure 13 shows photographs of this imagery. Although, the system may not have been in perfect alignment, the "waviness" of the characters and loss of pixel definition further suggest the lack of system geometric precision.

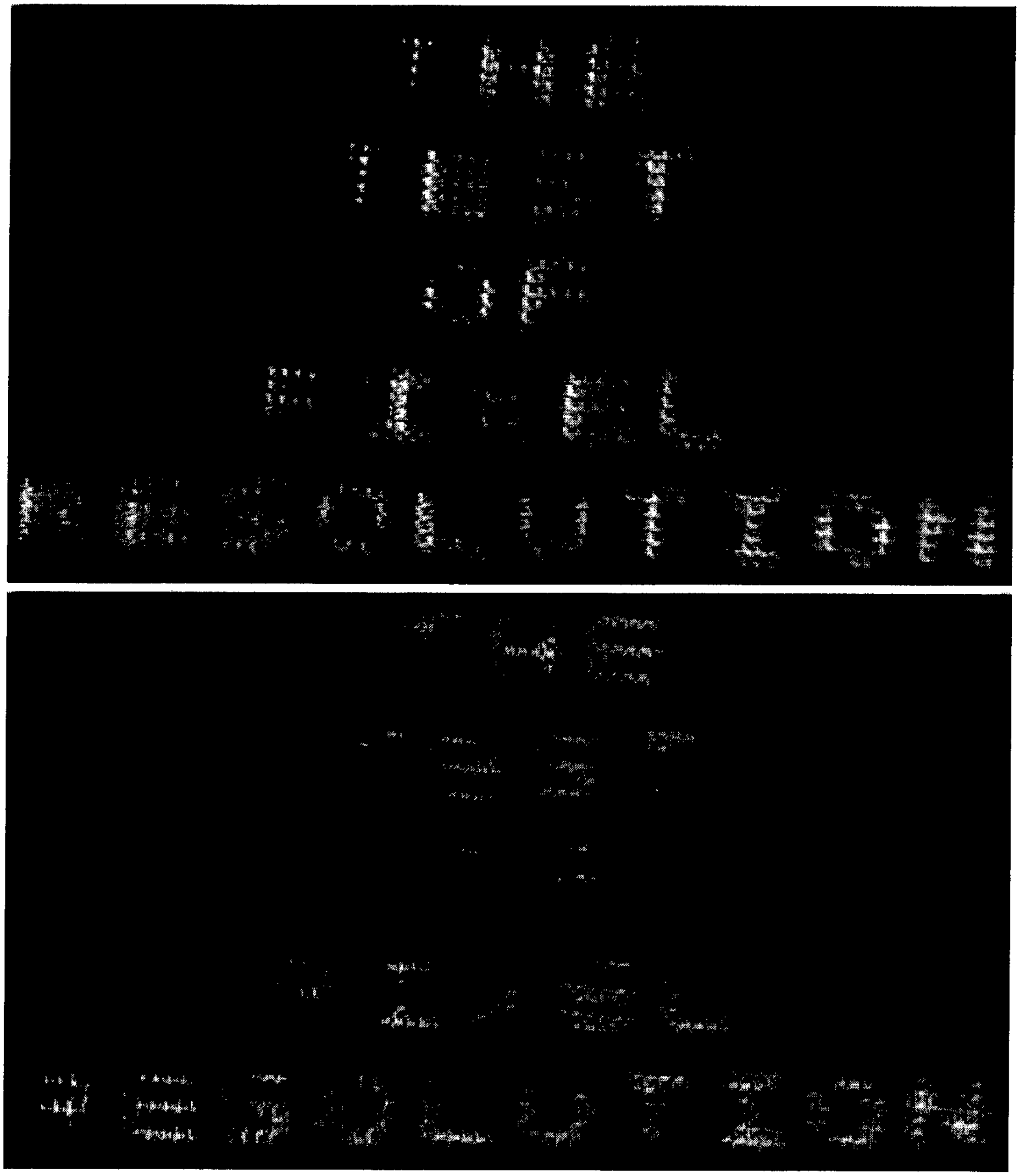

Figure 13. Photographic images of 5 by 5 character sets presented normally (bottom) and 90 degrees rotated (top). Note the slight misalignment of character elements.

Summary

The data reported here show an improvement in the MTF, which meets the Comanche contrast requirement at the Nyquist frequency. Microvision's new electronics made possible this increase in modulation at the higher spatial frequencies (observed in the MTF and traditional CTF) when considering only those single orientation spatial

frequencies. However, when a noise analysis is used, we saw that the horizontal MTF's modulation at the Nyquist limit was handicapped by the noise modulation. The perceptual relevance of this noise pattern is revealed in the inability to identify the orientation of the vertical grill pattern at this frequency.

Explaining some of the differences observed between Microvision's measurements and our own is more difficult. Certainly the noise level of our camera may play a role. Additionally, we noted in Microvision's captured images that gray level representation of luminance was limited to about six bits (gray levels of 0 to 63) even though they reported using a 12-bit camera. In our measurements, we made it a point to drive the system as hard as we could without saturating our camera.

The HMD's inability to hold calibration/alignment is a major concern. A contributing factor is the system's complexity; there are a large number of subsystems that must perform optimally in order to produce quality imagery.

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Harding, T.H., Martin, J.S., Beasley, H.H., and Rash, C. E. 2001. Final phase I evaluation of the Microvision, Inc. Aircrew Integrated Helmet System HGU-56P scanning laser display. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2001-06.

Appendix.

List of manufacturers.

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